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ABSTRACT

The independent Waterford School in Provo, Utah, opened in September 1981, with the goal of providing, through technology, all children with an excellent education. Additionally, it intended to demonstrate how computers could best be used as part of educational delivery. School administrators have found that computerized instruction is improved by a professional educational computer system delivered in a room separate from regular classrooms and managed by a full-time professional. Teachers are enthusiastic about computerized instruction and make it an integral part of their role by exposure to the computer curricula and by taking an active role in computerized instructional delivery. In addition, it was discovered that the use of an instructional management system is a key source of discoveries about student learning and that many liabilities of traditional educational assessment and guidance are overcome through the use of computerized adaptive testing. Finally, the effect of the computer is to liberate teachers and students (who can effectively spend up to an hour per day in computerized instruction) from many of the traditional aspects of their roles, thereby enhancing creativity and encouraging a responsibility for learning. (MLF)

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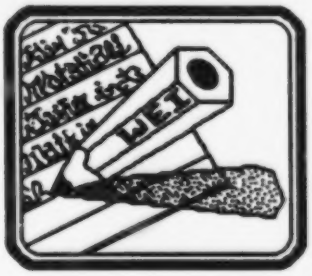

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Lessons from Waterford

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What happened at the Waterford School in late April 1985, while predictable, was also perplexing. During a faculty meeting, the director of the Lower School reported a situation that had emerged in her fourth-grade class. It seems that the range of her students' progress, particularly in mathematics, had become uncustomarily large. Some students had moved well beyond traditional fourth grade boundaries and were bringing a level of sophistication to the classroom that was, in her experience, unprecedented ("talking like mathematicians" was the way she put it). While she was pleased by this turn of events, it was not without perplexity. "I'm not quite sure how I'll handle it," she remarked. Then she added, "But I know that it's the computer that's done this."

The response of others at the meeting was sympathetic. Many nodded knowingly and proceeded to share their own stories of unforeseen developments among their students, of challenges created by the computer. Though the meeting may have been considered a confrontation, it was not a clash of opinions or personalities, but rather a case where a group of dedicated and resourceful teachers grappled with the newest development in an evolving experience of education.

In retrospect, that meeting, like others before it, was probably inevitable. To understand this, it is necessary to trace the history of the Waterford School and to take stock of the lessons that its history teaches. They are lessons with importance for teachers and school administrators, for educators generally, as well as for parents and their children. The lessons are especially important at a time when many people consider public education to be imperiled.

The Beginning

The Waterford School opened its doors for the first time in September, 1981. It had been founded with a single goal: Through the use of technology, to provide all children, even the poorest, with an education equivalent to the finest available. Waterford was to be an independent school and was designed to serve as a model for public schools. Additionally, it was to take the lead in demonstrating how computers could best be used as part of educational delivery.

Given this charter, efforts were made to approximate certain aspects of public schools. Faculty members were recruited from the area's public schools, as were students. This occurred through a public meeting that was announced in local newspapers. Parents who attended the meeting heard details about the new school and had the opportunity to fill out application forms. These were subsequently reviewed by an admissions committee consisting of two members from within the school (faculty and administration) and three members outside it. The primary objective of the committee was to provide a socioeconomic diversity in the student body that was representative of the surrounding community.

The school plant was a former parochial school (K-12) that had experienced a few changes of tenants prior to Waterford's arrival. In addition to a pair of classroom wings, the facility provided space for administration and faculty offices, a gymnasium (with stage), parking lots, and a playing field.

In its first year, the Waterford studentbody consisted of grades K-5 (the Lower School). The Middle School (grades 6-8) was formed in the following two years. Since then, each year hasbrought an additional grade, with the result that Waterford will graduate its first class in 1987. In January 1986, a preschool for three- and four-year-olds began, further extending the scope of the Waterford experience. With a section size (25 or more students) similar to that found in public schools, and with one section per grade level, the 1986 Waterford studentbody numbers approximately 350.

Beyond housing a diversity of ages under one school roof, the outward signs of Waterford's distinction from public schools have remained few. Students in the Lower, Middle, and Upper Schools are identified by their dress codes and by a homework load that is typically heavier than that of their public school peers. Otherwise, they have a school-day schedule, an annual calendar, and programs of extracurricular activities that are very similar to those found in public schools.

In matters of curriculum, however, there is a significant divergence, not so much in subject areas as in instructional format. Waterford's curriculum tends to the traditional liberal arts for virtually all students at all levels -- reading and literature, language arts (mechanics and composition), mathematics, science, social studies, foreign languages (required in Classes VI-X), the fine arts, and physical education. The principal difference comes in the latitude for learning extended to each student. It is here that Waterford's computers come vitally to view.

Lesson One: The Professional Computer System

Waterford's commitment to the use of computers for education is tied to a particular philosophy about the kind of computer that should be used. A considerable amount of research and analysis had occurred prior to Waterford's inception, leading its founders to conclude that the type of computer system best adapted to whole-school integration was a professional system. Such a system stands in marked contrast to the personal computers currently found in many schools. The professional system has very large storage capacity as well as high speed, and can interact with many students simultaneously. It employs voice-quality audio, complex graphics, and animation in those interactions. It is capable of maintaining an "audit trail" for each student -- a permanent record of its interactions with the student -- that can be made available in a variety of forms to teachers, administrators, and other education specialists. In addition, it provides a sophisticated authoring system for the production of new, special-purpose instructional materials.

With such features, the professional system offers a number of advantages over personal computers in either "stand-alone" or networked configurations. Not the least of these advantages is the freedom from diskette handling that has been estimated to consume as much as 40 percent of students' and teachers' time where diskette-based personal computers are used. While networking personal computers may overcome much of this problem, the fact remains that the curriculum available in networks is typically little more than an assemblage of diskettes and, though there may be some additional management capability, the curriculum is fragmentary and discontinuous; it lacks an overall, integrative design. These limitations, together with others related to size and power, are major instructional disadvantages of networked computers.

By contrast, the curriculum resident on the professional system was designed to be comprehensive. What is offered as a

reading course for the third grade, for example, is just that -- instructional materials that span the entire third-grade year, not just highlights from a course or bits and pieces here and there. The contents of the course are finite, to be sure, but the instructional permutations that the professional system makes possible can stretch those contents to much farther limits than would otherwise be achievable.

The computer curriculum was not made available when the school opened but was systematically introduced midway through the first year. This delay was intended to allow an initial approximation to more normal school conditions (i.e., those of public schools) before the computer made its formal appearance. It also gave the faculty a chance to establish themselves, to gain familiarity with their students, and to in other ways prepare for the addition of computer instruction.

The installation of the first courses brought a number of memorable scenes. A great deal of development work had been compressed into a relatively short span of time in order to have the courses ready. Development teams worked around the clock, week after week, in a determined effort to make the deadlines for installation. In some cases, whole families stayed overnight at the school in order to have contact with developer-fathers and developer-mothers who could spend no time at home. Sleeping bags in the hallways and midnight pizza orders became the routine.

Finishing touches were still being applied when students first began to use the computer and changes here and there continued for some time afterward. The heroic efforts of the developers did not go uncommended, however. At a subsequent school assembly, the members of the various development teams were recognized as special guests, and studentbody and faculty rose spontaneously to give them a prolonged standing ovation.

At present, the following courses, some as large as 100 megabytes in size, are in use on the trio of professional computers (one for each level -- Lower, Middle, and Upper) resident at Waterford:

- Primary Reading (K-3; makes heavy use of audio)
- Reading Comprehension (4-10; based on "schema theory," with emphasis on higher-order thinking skills)
- Remedial Reading (in final development)
- Mathematics (K-8; mainly drill and practice)
- Middle School Mathematics (5-8; drill and practice; extended topics in pre-geometry and pre-algebra)
- Language Arts Skills (3-6; punctuation and grammar)
- Spelling (1-6; audio, with 7,500 words and word elements; emphasis on vocabulary building)
- Sentence Combining (3-6; compound phrases, parts of speech, etc.)
- Word Processing (all grades)
- Writing I (K-2; composition and word processing)
- Writing II (3-6; composition, word processing, and creative writing)
- Language Arts (7-12; grammar and punctuation skills)
- English as a Second Language (K-5; heavy use of audio)
- Typing I (K-2; audio)
- Typing II (3-6)
- Typing III (7-12)
- French I (7-9; heavy use of audio)
- Geometry (7-9; includes a proof-checking capability)
- Algebra I (7-9; includes function-plotting and equation-solving capabilities)
- Algebra II (8-10; features like those in Algebra I; pre-calculus and trigonometry)
- Computer Literacy (6-10; uses the BASIC language)
- Interpretive PASCAL
- Chemistry (9-12; in final development)

Lesson Two: The Computer Room and the Computer Room Manager

While the choice of computer system preceded the establishment of the school, a further decision involved the location of the computers within the school. Each system was equipped with 30 student workstations that could be distributed among the various classrooms or clustered in a single room dedicated to computer instruction. The faculty chose the latter arrangement. They were concerned that having the computer in the classroom would divert attention from the regular curriculum. Placing the computer in a room of its own would maintain the distinctiveness of the classroom and allow them to concentrate on activities there.

On the basis of the faculty's decision, one classroom in each division of the school has been designated a computer room. The rooms are outfitted with individual cubicles around the perimeter. The central portion of the room has been left open, allowing an area for presentations, group instruction, etc. Each of the cubicles holds a terminal, keyboard, and headphones. The computer and its main terminal have been positioned either against a side wall or in a corner, slightly apart from the student workstations.

As was noted earlier, the computerized curricula became available at the conclusion of the first term of Waterford's initial year. The decision as to how the computer would be utilized was made by the faculty after considering a number of alternatives. It was, for example, possible to schedule computer instruction in either massed or distributed fashion -- having it occur all day or for much of the day on one day a week, or for shorter periods on several days during the week. Moreover, computer instruction might occur for part of the class at a particular time and for the entire class at other times. As might be expected, there was a considerable question in the early going as to whether younger children were capable of the type of interaction required by the computer. Could they, for example, learn to use the keyboard? How long could a computer session last before they tired and lost interest -- five minutes, ten?

Waterford's answers to these questions may surprise. Results show that younger students' facility with the keyboard progresses rapidly, to the point that first- and second-graders have achieved a typing speed of 15-20 words per minute. Also, the duration of the computer session is not so limited as originally anticipated. Sessions at Waterford are 30-60 minutes in length at all grade levels. Interestingly, time with the computer seems to be more efficiently used -- a point made by teachers and echoed by students, who have sometimes commented that time seems to pass more quickly in the computer room.

The early acquisition of proficiency in interaction with the computer was pointed out during a visit to Waterford by a high-ranking school official from a large eastern state. The visitor spent time in the computer room while the kindergarten class was there and was amused by the sight of the roomful of little ones (whose feet dangled well above the floor) absorbed in

their work on the computer. He sat at a workstation between two of them and was assigned some material from the reading curriculum. The visitor glanced a few times from screen to keyboard in order to orient himself and, in the process, was interrupted by the five-year-old on his left. The boy, with headphones still in place, gave him a knowing look and said, "Mister, if you need any help, just ask. I know all about these things."

There was an expectable mix of reactions to another early issue, namely, whether the teacher should be responsible for the operation of the computer. Some felt apprehension at the prospect of this responsibility. There was concern that they might somehow damage the computer; others were overwhelmed by what they perceived as the hopeless complexity of the operating instructions. While there were those who viewed these challenges as stimulating, there was a generally expressed preference to leave the details of the computer operation to others.

Consequently, the faculty voted to have a paraprofessional manager present in the computer room. In essence, this individual would be a teaching assistant, responsible to assure that students received the computer instruction they had been assigned and to respond to questions or problems that arose while students were in the computer room. This decision also provided faculty members with the opportunity to divide their classes in such a way that part of the class worked in the computer room while the remainder stayed with the teacher. At some point during the time allotted for computer instruction, the two groups might exchange locations. This arrangement seemed an effective step to more individualized instruction, allowing teachers the opportunity to devote attention to smaller groups of students for a concentrated period of time.

For the faculty, a further advantage to the presence of the computer room manager lay in the teacher's freedom from anxieties related to the use of computers. The manager would effectively buffer the teacher from the technicalities of the new technology, allowing it to benefit the students while not interfering with the teacher's instructional role. In effect, the student now had two teachers -- the classroom teacher and the computer -- each separate from the other.

The arrangement involving a computer room manager contrasts with most instructional settings involving personal computers. There it is typically the classroom teacher who oversees the technical operation and must therefore be trained in that operation -- a sore point with many teachers, who consider such tasks to be a frustrating consumer of time and an inappropriate amendment to their role. The Waterford solution spared teachers this chore. In addition, the expertise and continuity provided by the computer room manager contribute to greater efficiency in many of the logistical aspects of the computer's operation--e.g., troubleshooting hardware and software problems, creating "backup" copies of student records, generating reports, assigning curriculum lessons to students' terminals, etc.

Lesson Three: The Teacher In The Computer Room

While part of the logic to the establishment of a computer room, with its manager, was to maintain separateness between computer instruction and the classroom curriculum, it was anticipated that teachers would nevertheless spend much of the computer session in the computer room with their students. In reality, this development occurred rather slowly. Various reasons can be offered. The competence of the computer room manager may have made it seem less critical for the teacher to be present. The opportunity to devote special attention to a small group of students in the classroom while the rest were with the computer was advantageous. So, too, was the extra time for preparation that became available when the entire class went to the computer room and the teacher remained behind.

In time, however, the faculty became increasingly curious about the computer room experience. There were anecdotes about their students' learning told by the computer room manager. More and more, students would refer to things that they had learned during computer sessions. Teachers sensed a growing need to be more fully apprised of what was occurring during those sessions, and it became apparent that this would require their fuller presence. In addition, there was a growing realization that the two curricula--classroom and computer--were not as separable as had been previously assumed. While it had been convenient to treat them that way, an integration of the two was now clearly called for.

Consequently, in Waterford's second year, teachers began to regularly accompany their students to the computer sessions. In addition, staff development began to focus on teachers' familiarity with the structure and contents of the computer curriculum. Increasingly, the faculty came to terms with what was now recognized as a compelling need and one that would require their ongoing effort in the years ahead. It was imperative that an integration occur between what students were learning in the computer room with what was being taught in the classroom. The development of strategies for coordinating instructional activities in those two settings had finally come to prominence in the faculty's agenda.

While this need may seem obvious in retrospect, it points up the inertia of tradition that had to be overcome in order for the teacher's role to be significantly affected. In its own way, the computer room served as a lens that gradually amplified the teacher's awareness of the learning process at the level of the individual student. This occurred as teachers observed students' work at the computer. Such observation would, sometimes in short order, clarify the kinds of problems that existed. A few minutes spent with students at that critical point might have immediate effect in terms of improving their understanding, motivation to learn, and ability to move on. While such insights could also occur in the classroom, they were often not so likely there. Classrooms did not so conveniently provide opportunities for unobtrusive observation nor could the teacher intercede there on an individual basis with the same impunity that the computer room afforded. Individual attention of that sort in the classroom typically meant the disruption of instruction elsewhere. In the computer room, the computer absorbed the responsibility to provide ongoing instructional activity, releasing the teacher to concentrate on students in need.

Classroom and computer room instruction directed and reinforced each other to an increasing extent. As a result of their computer room experience, teachers could use classroom time more advantageously, capitalizing on what the computer had already presented and focusing on material that their observations had shown to be particularly problematic. Alternately, classroom instruction was used to set the stage for computer room instruction, to "prime" students for what they would next confront on the computer. At other times, the computer materials were utilized for drill and practice to reinforce concepts introduced in the classroom. It became obvious that there was a large set of possible ways for linking computer room activity to that in the

classroom. The faculty had already identified initial members of that set and would, with time, fill in more and more of it.

At the same time the faculty were responding to the possibilities associated with their involvement in the computer room, a bond was developing between them and the computer room managers. Who better to share their discoveries with than someone already intimately acquainted with the computer curriculum and whose own experiences in the computer room were resonant with the teachers'? Instead of remaining a distant component of the instructional process, the computer room manager was increasingly a colleague and consultant, encouraging the sharing of successes and providing a sounding board for new ideas. The teacher and manager together established the schedules for computer room instruction on a weekly basis and sometimes more often. With this coordination, managers could assure that the desired instruction was available to students as soon as they entered the computer room, thus contributing to their overall "time on task." In addition, managers continued to assist teachers by observing students' work in the computer room and helping with problems as they arose. It was not unusual for managers to be assigned to work with particular groups of students and in other ways to contribute to the overall learning experience.

While the initial selection of Waterford faculty had occurred without regard to their experience with computerized instruction, many of them might now be considered experts in the field. At this point, however, the integration of the computer into their teaching is sufficiently seamless that it is difficult for them to make statements about its unique impact on their teaching or to otherwise categorize the determinants of their performance (e.g., "What does the computer contribute vs. what you contribute?"). Suffice it to say that faculty members are staunch advocates of the advantages to be gained when the computer becomes a part of the instructional system as it has at Waterford. In recent interviews, several of the teachers were asked how they would feel if they had to return to the positions they held before coming to Waterford. Almost all of them considered the prospect traumatic, saying that it would be nearly impossible for them to return. Said one, "I could never go back, knowing what I do now. Being at Waterford has made me a different teacher. I don't see how I could possibly go back. I'd have to take the computer with me."

Lesson Four: The Use of Management Reports

Perhaps no development galvanized faculty interest in the computer more than their utilization of the instructional management reports. It is one thing for the computer to provide instruction but quite another to track student performance in terms of such things as:

- Number of lessons attempted
- Number of lessons mastered
- Ranking in the class in terms of mastery
- Current position in the lesson sequence
- Amount of time spent per lesson
- Proportion of time spent in particular instructional activities
- Number of times an activity was exited

With further development of the computer curriculum, more and more of these report options are becoming available to teachers, together with reports of aggregated performances (e.g., the performance of a particular subgroup of students or of the class as a whole). While the reports are available at any point, in the early going they were routinely provided by the computer room manager in weekly sets.

It may have been the sheer volume of the reports or perhaps their technical appearance that stalled the facultys' interest in them initially. However, once training in the interpretation and application of the reports was included in staff development, there was a rapid upswing in their use. Teachers typically need no convincing that diversity exists among their students. The management reports documented that diversity in a variety of ways but, more importantly, gave Waterford teachers the capability for a constructive response to that diversity. For example, by looking at a report, a teacher could determine where a student was in a particular sequence of lessons, and whether the student had been at that point sufficiently long to arouse suspicion. An excessive amount of time spent in a particular activity could be an indication that the student had reached an impasse, that there was some oversight or some failure of understanding that stood in the way of further progress. Accordingly, the teacher could plan to spend time with that particular student in the computer room, reviewing the material in order to discover what the problem was and how it might be best resolved. Sometimes excessive time spent at a certain point in the curriculum might also indicate that a student was simply wasting time. Here the teacher's tack might involve a word of encouragement -- gentle or otherwise.

The use of reports to determine a student's current status in the curriculum and the implications of that status for intervention by the teacher could be viewed as a "first-order" category of use. A further, "higher-order" use is made possible by the fact that the professional system also maintains a cumulative history of each student's interaction with the computer from the point the student is first registered on the system. Thus, the management record can span an entire school year and could be extended over multiple years. This longitudinal "trace" report of students' progress through the curriculum is a virtual treasury of data on the learning process. By stepping back and taking a "wide-angle view" of a student's history, it is possible for the teacher to perceive the presence and persistence of characteristic patterns of interaction with the instructional material -- what might be referred to as students' "learning preferences" or "learning styles." After a while, experience with trace reports can conceivably give a teacher the ability to categorize these patterns and to sense which of them are productive and which may be detrimental.

There was, for example, the case of a student who gave every impression of being actively involved in her work, whether in the classroom or the computer room. However, her grades consistently fell short of teachers' and parents' expectations. Analysis of her trace report revealed that even though she had "logged on" to the computer for every computer session, she actually spent very little time in direct interaction with it, i.e., her time on task appeared far less than that of the other students. Closer observation revealed that she had become very adept at disguising her dawdling. She spent a great deal of time daydreaming, though not in conventional, easily identified ways. Similar close examination of her classroom behavior showed the same thing. The teacher, now alerted to this situation by the trace report, shared the report with the girl's parents and, with their help, was able to motivate her greater concentration on school work.

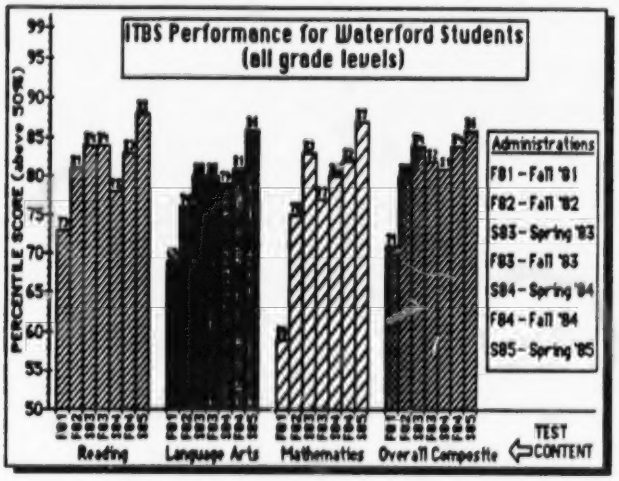
Another teacher noticed a curious effect in one of her student's reports. Like others, he would spend an appreciable amount of time in the practice portion of a lesson prior to moving to the mastery segment (that segment, which, if passed, would allow a

student to move on to the next lesson). However, he had a tendency to quickly exit from the mastery segment, with the consequence that he was making little progress between lessons. Instead, he spent his time switching between various strands in the course. In conversations with the boy, the teacher learned that he was extremely sensitive about the mastery evaluation and, rather than risk a negative outcome, chose to avoid being evaluated. This discovery made some of the boy's classroom behavior more understandable and led her to work with him in learning to take risks without affecting his self-esteem. In fact, her experience with this student prompted the teacher to focus on the issue more generally with her entire class.

A number of intriguing possibilities had unfolded. Instead of concentrating almost entirely on the "what" of learning, i.e., on subject matter and its organization, with occasional allusions to the "whys" (e.g., "This is important because . . ."), the faculty now felt themselves in a better position to involve their students in discussions of the "hows." The management reports, coupled with seasoned observations in the computer room, provided a context for teaching about learning, for helping students "learn about learning." Students were given a new way to talk about their learning, to become more conscious of what they do when they learn and, in the process, to adopt more productive practices. At this point, a further challenge lies in the development of a taxonomy that will adequately represent the diversity of learning patterns revealed by the computer and, ultimately, in the construction of curricula that will be readily adaptable to such diversity.

Lesson Five: Computerized Adaptive Assessment

Like most schools, Waterford has felt an incumbency to measure its students' academic achievement by traditional means. Consequently, standarized tests have been administered each year, typically in the fall and spring. For several years, the Iowa Test of Basic Skills (ITBS) has been administered in this "pre/post" fashion. Since the first year, the test results have been generally positive. The figure below shows the ITBS performance for the entire school over the four-year period of 1981-1985. While the gains were greatest between the first two administrations, there is an upward trend in the scores and, in the overall composite, a gain in the four years of 15 percentile points (the statistical expected gain is zero). Growth in scores in that period has been greatest in mathematics.



Another outcome of interest from Waterford's testing program involved discrepancies between measures of ability (i.e., aptitude or potential) and achievement. Prior to Waterford's first year, each student had been given a widely used test of intelligence -- the Wechsler Intelligence Scale for Children--Revised (WISC-R). The Stanford Achievement Test (SAT) was also administered in the fall and spring of the first year. After the fall administration of the SAT, there was a notable number of cases in which the SAT and WISC-R percentile scores were far apart. Typically, the achievement score fell appreciably below the intelligence score. In other words, many students seemed to be falling short of their potential for scholastic progress. Moreover, the size of this difference increased with grade level. However, by spring, the discrepancy between ability and achievement had mostly disappeared, with achievement rising to approximate potential. This was true of individual students as well as class averages.

The fact that standardized testing has continued over the years should not be construed as indicative of widespread satisfaction with such tests among faculty members. Their complaints, as well as those of students, have been consistent from year to year: (1) the tests take too much time, and (2) they often do not specifically address what has been taught. Clearly there was an established need for new tests that inform teachers about students' deficiencies vis-a-vis curricular contents while requiring less time for administration.

In exploring options to traditional tests, it was natural to turn to the computer, and, before long, a number of possiblities presented themselves. Chief among them was the use of the computer for adaptive assessment. What this meant was that, instead of exposing the student to a lengthy set of items that stretched across the entire range of difficulty, the computer would order the items "intelligently," with each succeeding item being selected on the basis of the student's response to the previous item. In this way, the test would adapt to the individual student instead of making one test fit all. The advantages of computerized adaptive testing include:

- Consistent accuracy of measurement across the entire range of ability or achievement
- Instantaneous scoring and rapid reporting of results
- Generally higher levels of motivation in students taking the test
- Much less time required for testing since many fewer items are required for any one student
- Improved test security.

A number of computerized testing instruments have been developed and are in use at the Waterford School. Each of the tests is briefly described below:

- **Waterford Test of Basic Skills.**
  An objectives-referenced series at grade level in major subject areas. The strength of the test is its linking of results to a prescriptions base consisting of both classroom and computer curricula. The computer prescribes an immediate course of remediation for objectives not yet mastered.

- **Waterford Preschool Profile.**
  An objectives-referenced test of school readiness suitable for use with children in the preschool years. This test is used in conjunction with kindergarten admissions at Waterford.

- **Waterford Reading Abilities Profile.**
  A more deliberately diagnostic test in several skill areas related to reading performances. The test is sensitive to a variety of reading disabilities

- **Waterford Learner Profile.**
  A hierarchically organized, objectives-referenced test of skills related to critical thinking and problem-solving: memory, pattern recognition, reasoning, verbal ability, attention, learning style, etc. The test can be given in a short form or can be elaborated in more narrowly defined skill areas.

- **Waterford Occupational Profile.**
  A job skills-oriented testing series appropriate for use with older students. In addition to specifying current job-related skills and competencies, the tests identify personal values and preferences related to work environments. There is also an assessment of career interests.

Computerized test development capability is also available at Waterford. Using the Make-A-Test program, a teacher can create tests specifically for the class and have them administered in the computer room or printed for administration in the classroom. The tests are scored by the computer and the results are entered into the management system, where they become available via a number of different reports.

Recent developments in California and Texas were an outgrowth of Waterford's role in the development of computerized educational assessment. Research studies were conducted in the spring of 1985 in several California school districts and involved segments of the California Assessment Program -- the statewide evaluation series. In addition to demonstrating the feasibility of large-scale computerized testing, the studies provided conclusive support for the greater efficiency of computerized testing and computerized adaptive testing in particular. The research design called for three versions of each test: paper-and-pencil, computerized (simply transferring the printed materials to the computer screen and replacing the answer sheet with the keyboard), and computerized adaptive. Several hundred students from two grade levels (third and sixth grades) were involved as subjects. Each student took two of the three possible forms of the test. The assignment of tests and the order in which they were presented were determined randomly.

Comparisons of student performance on the three versions of the test showed the following:

- For each grade level, estimates of a student's achievement did not vary across the three types of test. In other words, the tests could be considered equally accurate in measuring level of achievement.

- The average time required for administration of the paper-and-pencil version of the test was approximately twice that required for the computerized version. In other words, simply computerizing the test reduced the test administration time substantially. This may have reflected a difference in students' motivation due to the novelty of the computerized test. The effect was slightly greater for the third grade than it was for the sixth.

- The computerized adaptive test reduced the average time required for test administration still further--to approximately one-fifth of the time required for paper-and-pencil administration. Again, the effect was slightly greater for third-grade students. The dramatic decrease in testing time was attributable to the smaller number of items required for the adaptive test.

The first district-wide administration of a computerized test battery was conducted in the Garland (Texas) Independent School District in the fall of 1985. The test battery, known as PREDICTS, serves as the district's predictor of student performance on the statewide assessment and is similar in its design to the Waterford Test of Basic Skills. As in California, the tests were administered on professional educational computer systems. Approximately 5,000 Garland students in grades 3, 5, and 9 took the tests over a three-day period. Scoring and test reporting, including instructional prescriptions keyed to the district's curriculum were available soon after testing had concluded.

The success of these larger endeavors should not obscure the fundamental purpose for testing: to guide instructional delivery to meet the needs of the individual student. Oftimes the process involves discoveries that might not have occurred otherwise. Such was the case with a Middle School student who was involved in early pilot testing of the Waterford Learner Profile. Her academic performance had to that point been erratic, seeming to reflect a greater interest in social activities at the school. While taking a test involving visual concepts, she mentioned to some of the test developers who were present that there were errors in some of the items. They were intrigued by what she had identified as error and, in analyzing her observations, realized that they were remarkably insightful. She had, in fact, seen things that they had not and was the only one to have done so.

This incident soon became common knowledge among the young woman's teachers, who thereafter took special interest in her unusual ability. She was responsive, in turn, and exhibited a new-found confidence in her academic abilities. "I always knew I was smart," she said. "I just didn't have any way to show it."

Lesson Six: The Liberation of Teaching and Learning

If there is a consistent theme running through the lessons and anecdotes from Waterford shared here, it is the theme of liberation. Teachers and students have been freed from certain traditional constraints. In important ways, their liberation has come through the computer and its ability to individualize the educational experience. It is this punctuation of individuality, this respect for individual natures and individual potentials, that is very much at the core of Waterford's philosophy and part of the heritage of educational innovation over many centuries.

Waterford's computers and the instructional, assessment, and managerial capability they contain are part of the overall educational delivery system that the school represents -- a system that may be considered unique. The major effect of the computers, as frequently reported by the teachers, has been to allow them to accomplish more than they could otherwise. There has been a "work bonus" conferred by the computers that translates into greater teacher productivity. Because the computer is capable of doing so many things and doing them quickly -- things that would otherwise absorb teachers' time and energies -- the faculty find themselves able to move beyond the traditional pace and pattern for instruction and work more creatively as well as individually with their students.

Teachers, for example, have long been concerned with the problem of forgetting, i.e., with the issue of preserving learning so that it is not lost. They want to know about the optimal delay between initial presentation of material and subsequent review. How often should students review material in order to prevent their forgetting it? Conventional instructional plans generally prescribe review intervals that have the average student in mind. Therefore, reviews may come too soon for some students (those who have not yet begun to forget) and too late for others (those who long ago forgot). Building on current instructional management strategies, developments in the computerized assessment of learning may well provide individualized "decay functions" for learning, patterns of forgetting identified for individual students that can be used to prompt review. Such prompts could either be incorporated in the planning of classroom activity or in automatic review sessions provided as part of computer instruction. Regardless of the mode of implementation, the learning decay function would constitute a further contribution by the computer to the teacher's productivity.

Just as the computer can be shown to benefit teacher productivity, it can also contribute to learner productivity. Consider the issue of individualized attention. The amount of attention that is directed to an individual student in a current public school classroom of conventional section size can be estimated to be ten seconds per hour or one minute per school day. (This assumes that a teacher spends an average of five minutes of each classroom hour in individualized instruction.) By contrast, every Waterford student spends between 30 minutes and an hour in individualized interaction with the computer each day--30 to 60 times the amount of individualized attention that would normally occur--and this in addition to the individualized attention available in the classroom. With the ability to provide such a striking increment in attention to the individual student, the computer can obviously make a substantial difference to the efficiency of student learning.

The computer's liberating effect is exemplified in other ways as well. One of the teachers in the Lower School has long advocated the position that students should have an active role in learning. She has been impressed with the computer's ability to displace the passivity that too often characterizes education. As part of her effort, she developed a model of student learning that has as its goal the establishment of "responsible learners." By this, she meant students who have learned to take responsibility for their own learning, students who have become both self-reliant and self-motivated in their learning.

To promote this condition in her students, she identified a series of stages through which the student must pass in order to lay legitimate claim to learning. Beyond the stages of presentation, discovery, practice, etc., lie the further stages of mastery (overlearning) and application. This last stage is perhaps most distinctive. For her, the ultimate demonstration that something has been learned comes when the student succeeds in teaching it to others. Application of that sort is prized.

In the midst of her fourth year at Waterford, she was observed standing in the hallway just outside her classroom wiping tears from her eyes. She had obviously been quite moved by an occurrence in the classroom. When asked about it, she reported that a pair of students had independently and spontaneously come to class that morning with items from home. These were not just any items but, in each case, had been purposely constructed by the students as illustrations of a particular concept in mathematics that she had been teaching over the past few days. They had brought their work for her to use in demonstrations to the class but wanted first to explain to her how it should be used!

On another occasion, the same teacher was approached by a pair of her students at the end of a school day. They had come to confess something. While the computer had certified their performance earlier in the day as adequate for mastery of a particular segment of instruction, they still felt some uncertainty about the material. In their opinion, they still had some more work to do before they would be confident of mastery and had come to ask the teacher for more time. For her, such a request signaled the responsibility that these students had accepted for their own learning.

The teacher has been deeply affected by these events. For the first time in a distinguished teaching career, her model has received confirming evidence. In one situation, students, on their own initiative, had applied their learning in a way that shared that learning with others. In the second case, students had independently recognized the insufficiency of their learning. To her, these were major steps forward. In looking back on the incidents, she gives a good share of credit to the computer: "What it does is put the stamp of authenticity on learning. The students receive something in the classroom and then they see it again in the computer room, and seeing it there gives it even more credibility. They can believe it. And, with this confidence, they can go into the world and find it for themselves there as well."

Lesson Seven: The Agenda Is Never Certain

While it is easy to turn rhapsodic in describing Waterford's accomplishments, there is a reality to them that can disquiet. Recall the confrontation cited at the beginning of this paper. The fourth-grade teacher had experienced a widening range in her students' progress, specifically in the area of mathematics. As a consequence of their experience with the computer curriculum, some of them were displaying a more advanced vocabulary -- "They're talking like mathematicians!" She had earlier decided to give them greater freedom in moving through the curriculum. An intrepid few had bounded ahead and when they came upon things that were unfamiliar, they turned to the curriculum's "Help" feature and found the pointers that enabled them to move still further. These students were learning largely on their own in this situation. Their experience set them apart from many of the other students in the class and required the teacher to address a greater range of interests and needs than had been customary.

Soon after this phenomenon appeared, the teacher examined the management reports for some of the students and discovered that they were on a pace that would soon mean the assigning of curriculum that had been ostensibly reserved for the fifth grade. Similar discoveries by other teachers ultimately resulted in the chorus of concern heard at the historic April meeting. The computer was documentedly an engine of variance.

It was not the case that the faculty resented what was happening or that they objected to it; rather, they were concerned to respond to this new development as productively as possible. What was plain was that their students had been "stretched" by the computer curriculum; the diversity in achievement had been accentuated to an unfamiliar extent. In the remainder of the meeting, a number of constructive suggestions were given. The faculty felt it important that the computer be equipped to provide them with performance groupings following each computer session so that they could, if desired, structure their classroom instruction according to those groups. In addition, they recommended that the computer print daily homework and classroom (seatwork) exercises according to individual performance differences and that the computer grade these exercises and store the results as part of the individual management records. These steps, and others to be added as the instructional management system is expanded and refined, were seen as potentially effective ways to accommodate the new realities of individualized instruction that the computer had helped to reveal.

At Waterford, one role of the faculty is to stimulate the further development of computerized instruction and instructional management. There was, for example, the early realization on the part of the kindergarten and first-grade teachers that the primary reading curriculum was inadequately "contextualized" for their students. It needed a much heavier helping of graphics and audio in order to be effective for younger students. The subsequent changes increased the size of the course materials three-fold (from 13 to 37 megabytes) on the computer's storage disk. But they now had the features the teachers had recommended. This iterative going-back-and-forth between school and the development shop describes the evolutionary aspect of the computer curriculum, the instructional management system, the computerized assessment materials, and many other components of Waterford's experience. Its climate remains experimental and conducive to continued discovery and refinement. While a certain amount of uncertainty in the agenda must be confessed, as is the case with any pioneering venture, there is nevertheless a soundness to the school that assures its citizens and impresses its visitors.

Waterford's vitality in pursuing its goals reflect a remarkable combination of factors. It is sponsored by a non-profit educational research institute and therefore does not require tuition for its support. The school's headmistress possesses strong organizational skill and articulates her vision of Waterford's role in the future of education in a manner that energizes and inspires the efforts of administrators, faculty, and students alike.

Certainly the faculty members themselves are crucial contributors to Waterford's success. Theirs is a cumulative knowledge that is unique. As they apply the lessons of Waterford and learn and share new ones, they will do much to establish the standard for educational delivery in the years to come. In addition to its full-time faculty, Waterford has been fortunate to attract outstanding members of the local university community to part-time positions (in mathematics and the fine arts particularly) and, in this way, has further broadened its perspective and enriched its offering.

Another vital ingredient in Waterford's success should not be overlooked. The parents of its students are an uncommonly talented and generous source of support. Parents are a conspicuous part of most school functions, assuming a variety of leadership and management roles, in addition to a great deal of the "behind the scenes" work that is vital to the school's operation.

In the near future, a second campus of the Waterford School will open -- the first of a number of planned replications. Also, Waterford will soon begin a community education program whereby children and adults from the surrounding community can come to the school in the afterhours and make use of its computer curriculum and assessment materials as well as its faculty resources for their own educational purposes. At the same time, Waterford will continue to host a steady stream of visitors from near and far, people with curiosity who have come in search of answers.

Conclusion

In summary, these are Waterford's lessons to date:

- That computerized instruction is improved by a professional educational computer system
- That computerized instruction is effectively delivered in a room separate from regular classrooms and managed by a full-time paraprofessional
- That, perhaps contrary to expectations, teachers are enthusiastic about computerized instruction and make it an integral part of their role
- That, together with the computer room manager, teachers should take an active role in computerized instructional delivery
- That students can effectively spend up to an hour per day in computerized instruction
- That successful staff development requires concentrated exposure to the computer curricula

- That the use of an instructional management system is a key source of discoveries about student learning
- That many liabilities of traditional educational assessment and guidance are overcome through the use of computerized adaptive testing
- That the principal effect of the computer is to liberate teachers and students from many of the tradtional aspects of their roles, providing a work bonus that enhances creativity and encourages a responsibility for learning
- That the agenda for future development, though uncertain, is nevertheless sound, reflecting Waterford's strong resources.

Chief among these resources, and Waterford's main reason for hope, is the commitment that characterizes and pervades its faculty, students, administration, and parents. Their pliancy and patience, their energy and eagerness, their sacrifice and spirit evidence the exceptional dimensions of the Waterford commitment. Though they may not fully realize what they are part of, they nevertheless empower Waterford in the pursuit of its dream: That, through technology, every child, even the poorest, will receive an education equivalent to the finest that is available. In that pursuit, new lessons await.

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